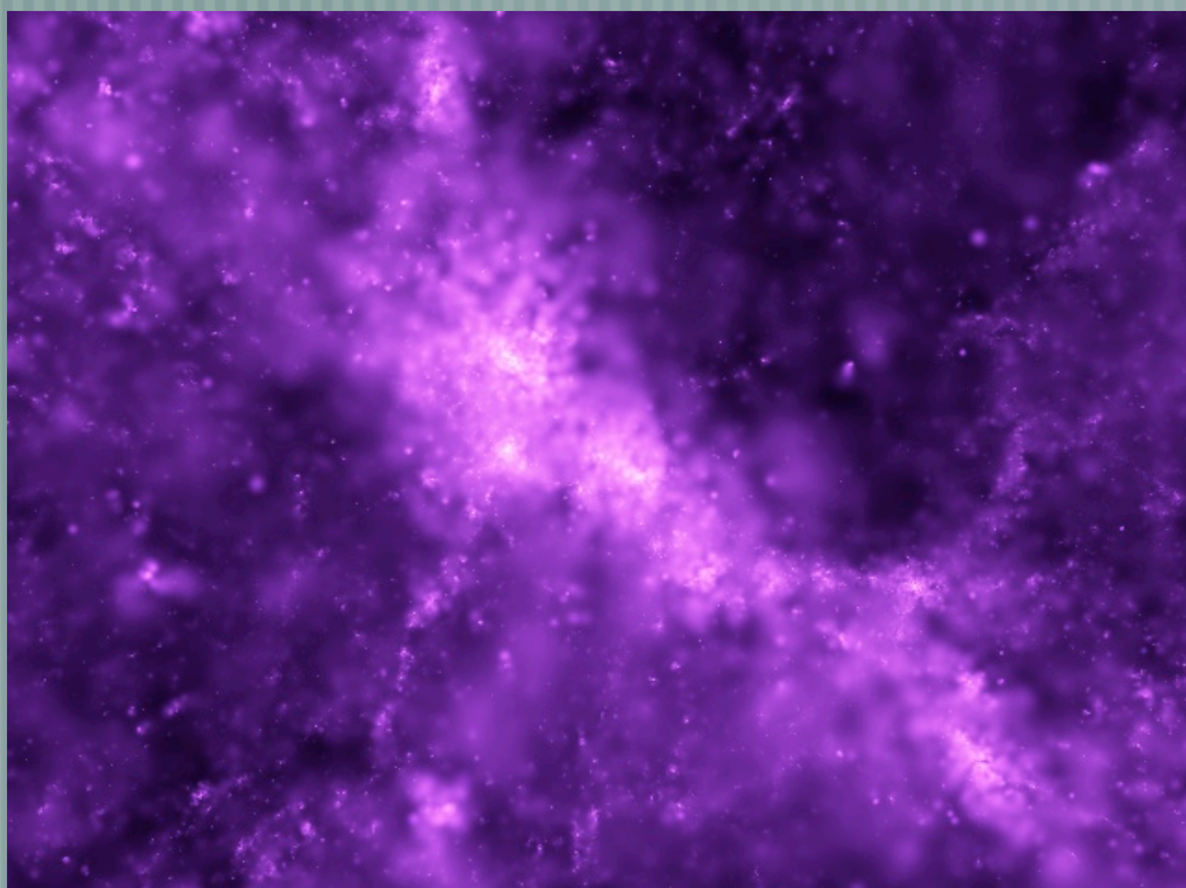
Population III star formation during and after the reionization epoch



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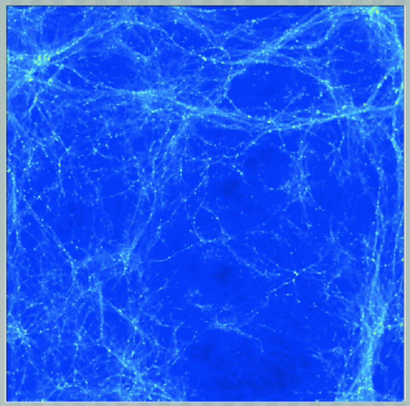
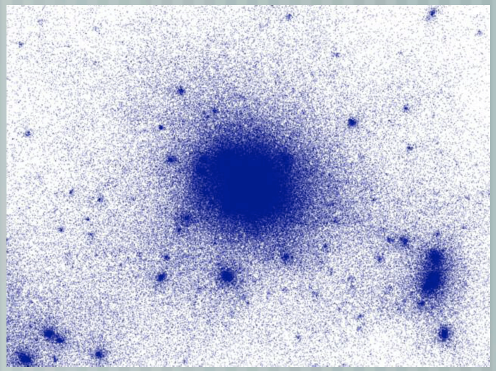
First Stars and Galaxies, 10 March 2010

Outline

- Star Formation During the Dark Ages: From Population III stars (metal free) to the First Galaxies (metal enriched)

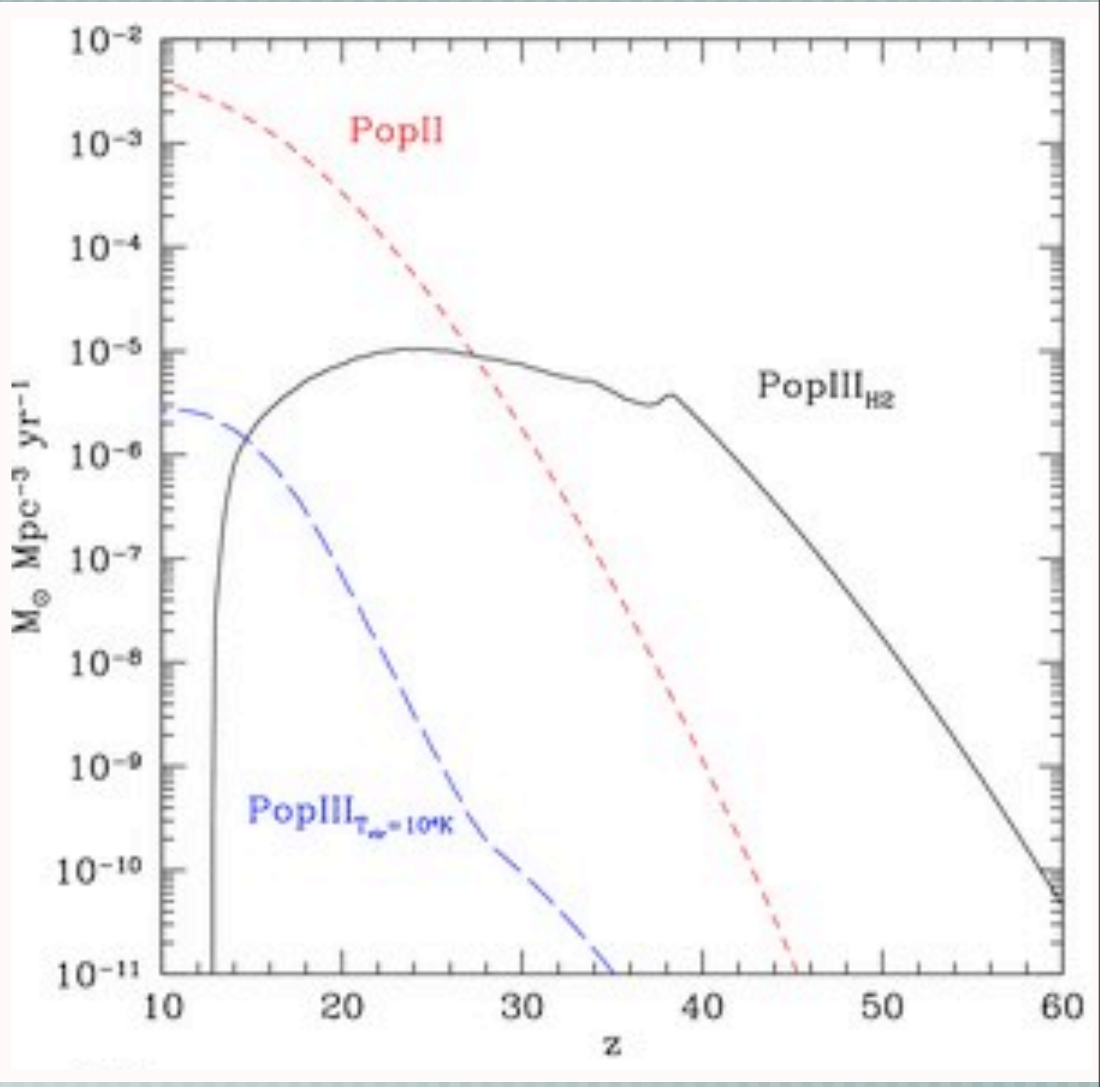


- PopIII/PopII transition in the Milky Way
  - Formation history of extremely metal poor gas and consequences for Galactic Archeology



The very first PopIII stars

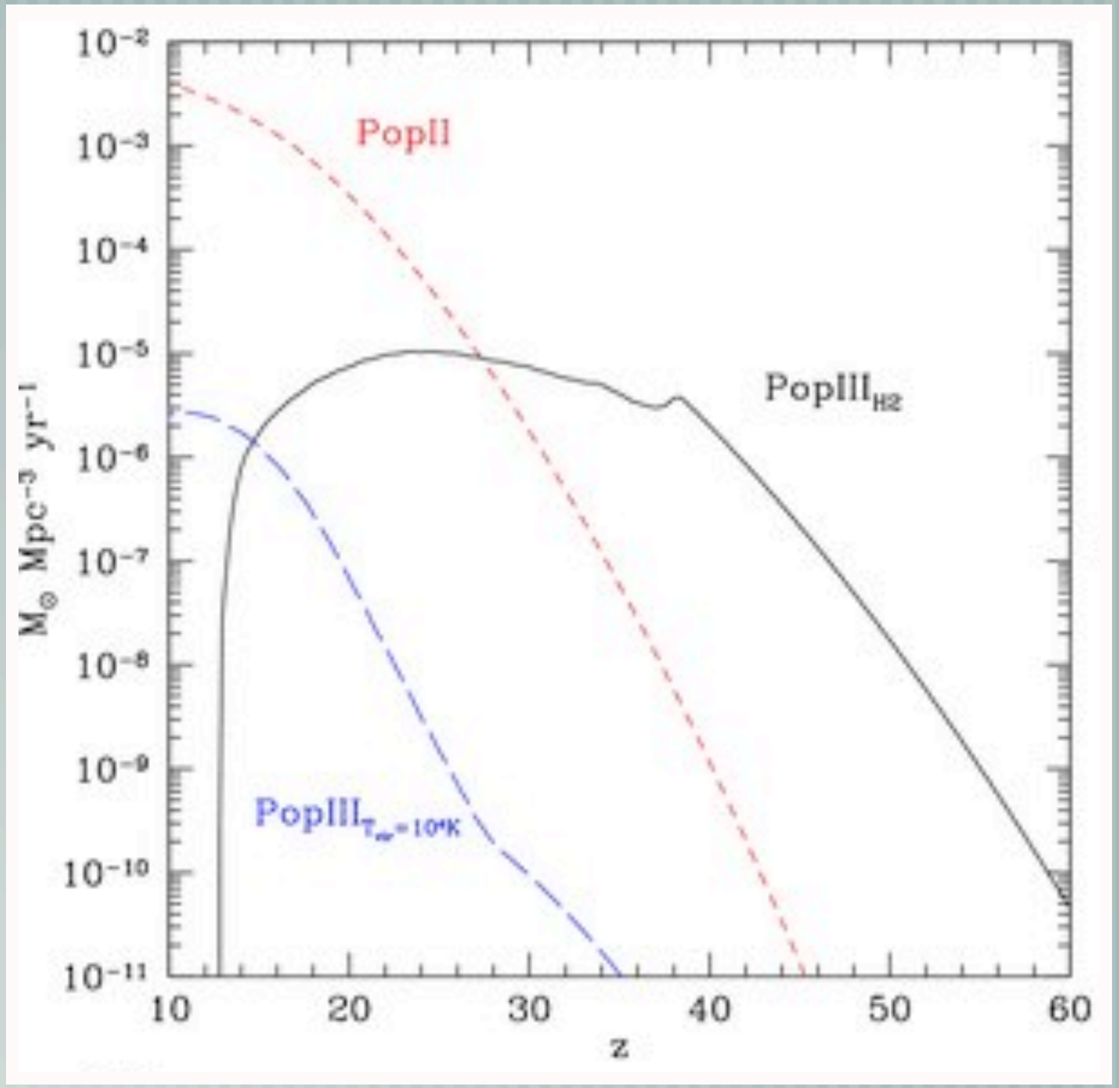
- PopIII stars first luminous objects in the Universe
- PopIIIs begin forming in minihalos ($M<10^6$ Msun) cooled by H_2 at very early times ($z>60$ - Trenti & Stiavelli 2007)
- Radiative feedback self-regulates their SFR after z~35 (Lyman Werner Photons photo-dissociate H_2): **End of PopIII.1!**



Trenti & Stiavelli (2009)

Population III star formation

- Metal enriched star formation takes over at z<25 !
- Still the bulk of metal free stars are formed at z<20
- PopIIIs can form at yet lower redshift in metal-free halos with $T_{vir} \sim 10^4$ K ($M \sim 10^8$ Msun, Lyα cooling possible)

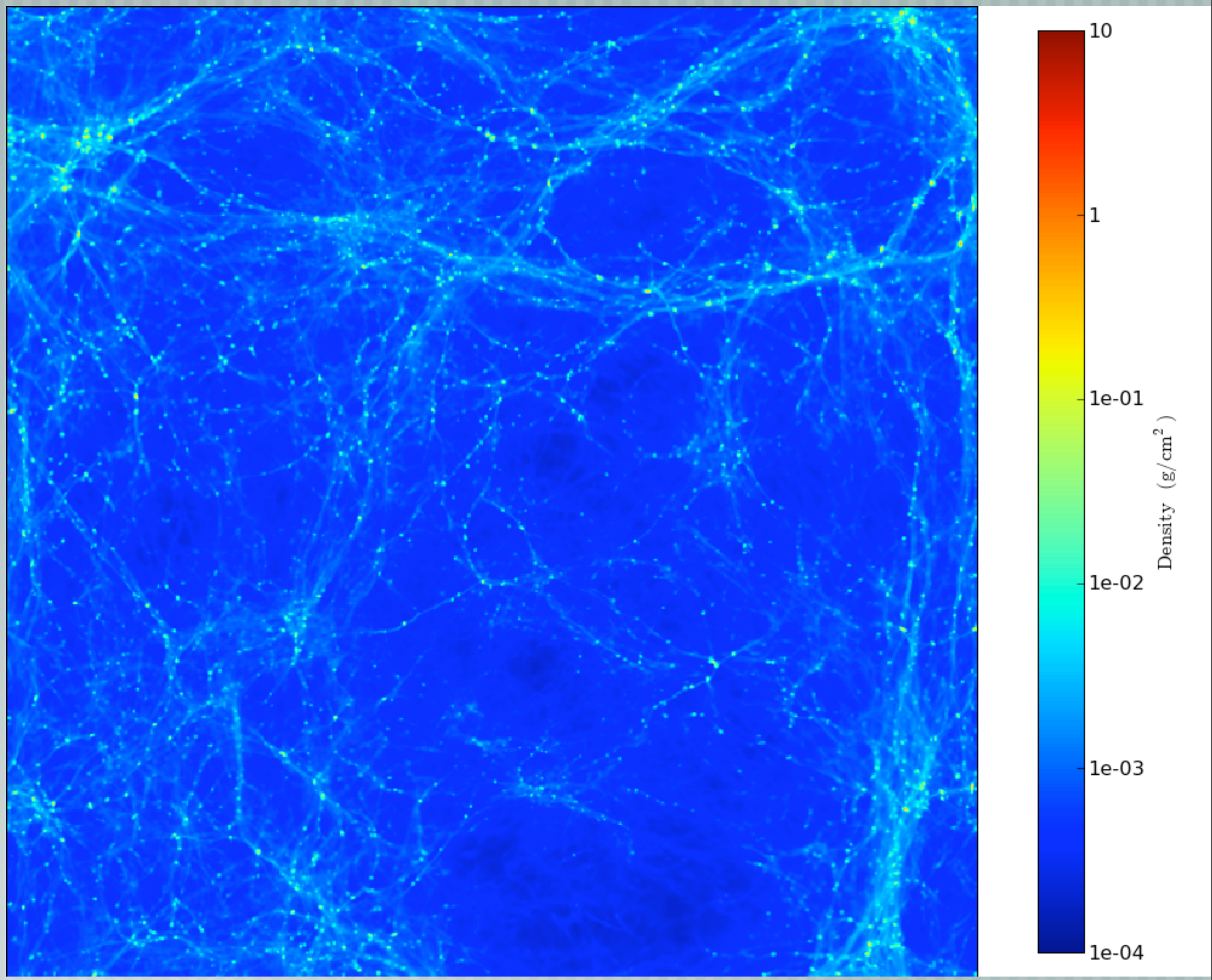


Trenti & Stiavelli (2009)

From First Stars to First Galaxies

- For detailed modeling at z<10, cosmological simulations are required
- Significant large scale structure present
- Coexistence of PopIII stars (in voids) and First Galaxies (in overdensities/protoclusters)
  - see Massimo Stiavelli's talk

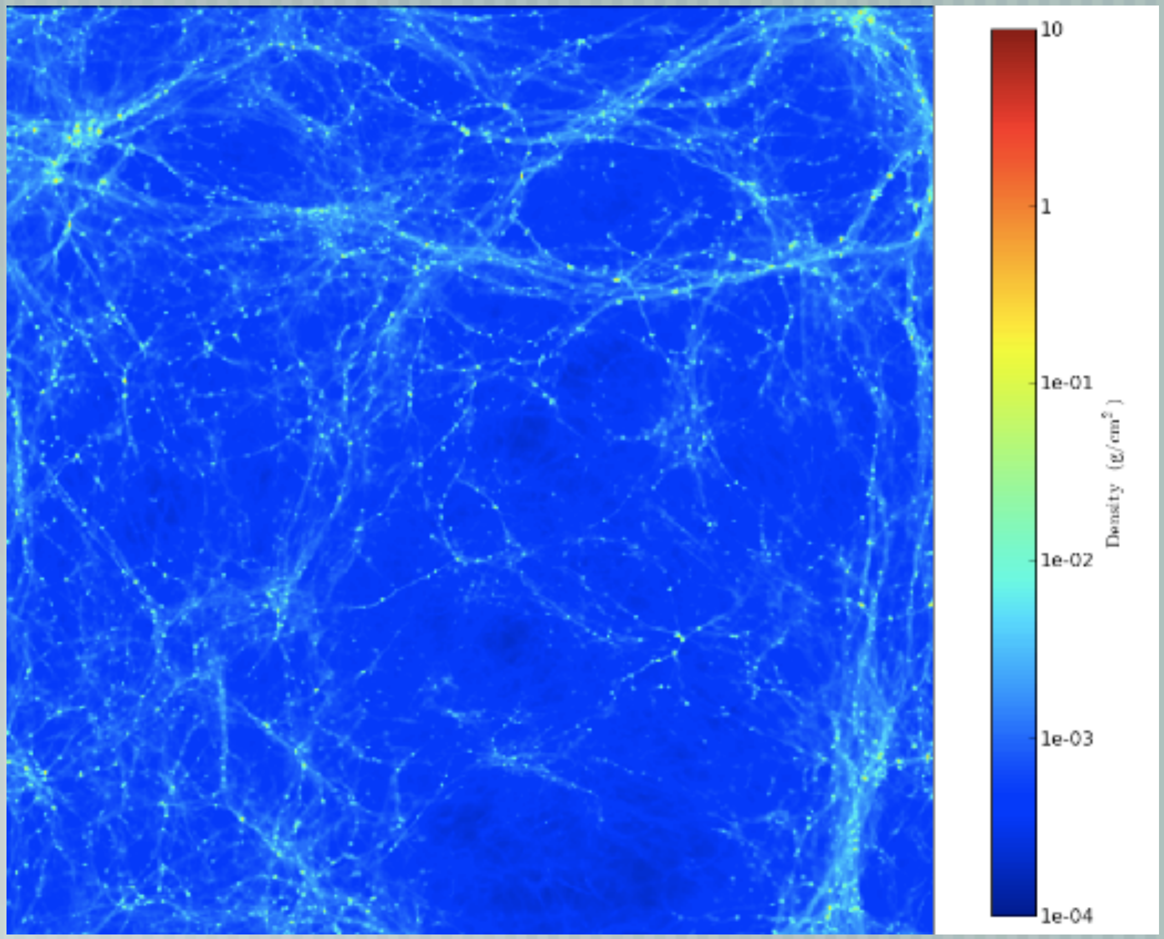
Structure at early times: density projection



10^3 Mpc^3 box, N=1024^3, z_{end}=6, Gadget2 Trenti, Stiavelli & Shull (2009)

PopIII stars at “low” redshift

- PopIII/PopII star formation regulated by:
  - radiative feedback (LW+ionizing)
  - chemical feedback
    - self-enrichment
    - metal outflows (not possible with analytical merger tree codes)
  - All these ingredients are included in our simulations

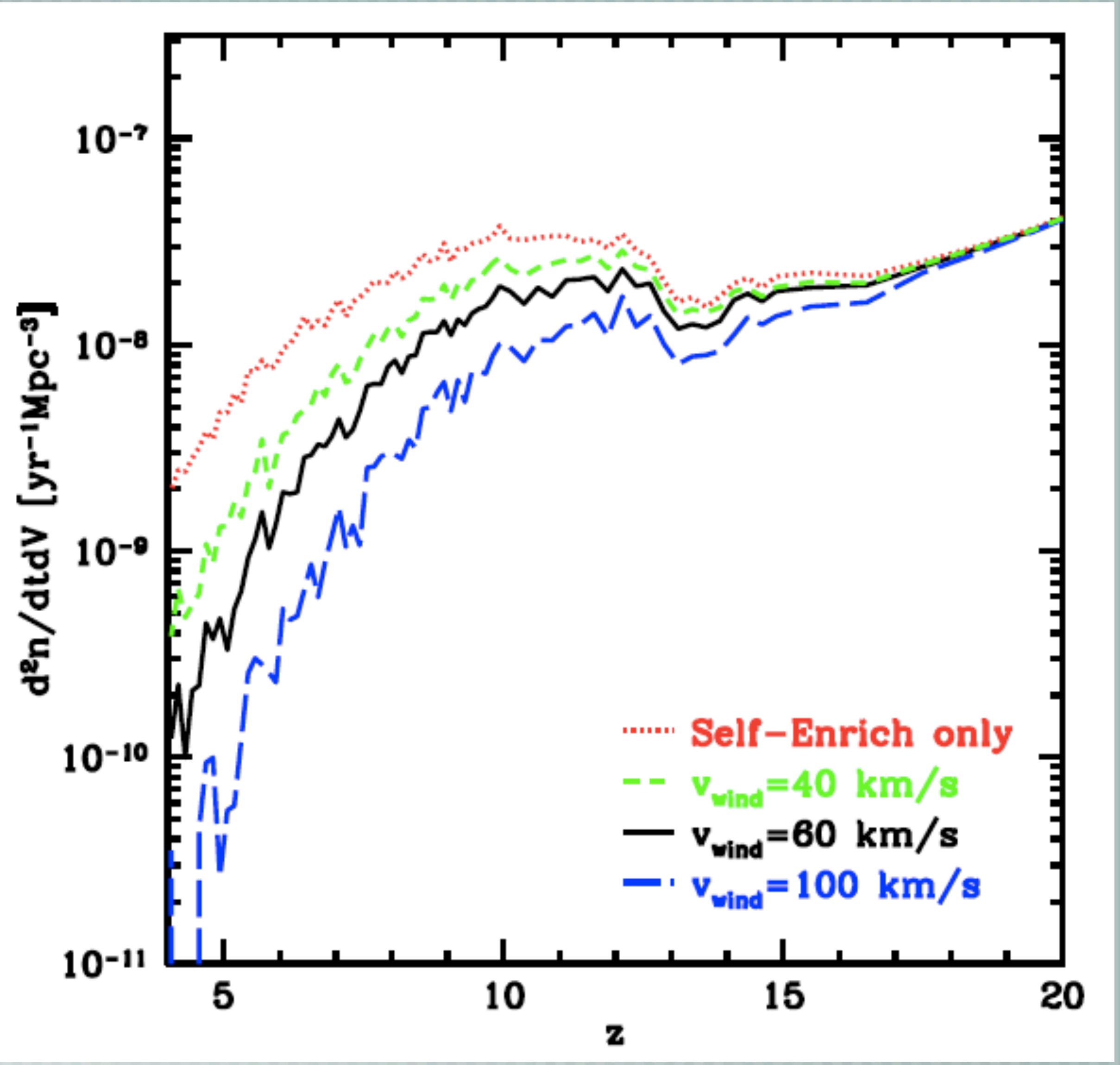


Trenti , Stiavelli & Shull (2009)

PopIII stars at "low" redshift

- Upper limit to PopIII SFR is given by self enrichment only
- Wind outflows from dwarf-like galaxies (M_{DM}~10^9 Msun) further reduce supply of metal-free gas
  - metal free star formation at "low" (z~6) redshift is possible, but very rare: ~1 PopIII Gpc $^{-3}$ yr $^{-1}$ (see also Tornatore et al. 2007)

Population III halo formation rate

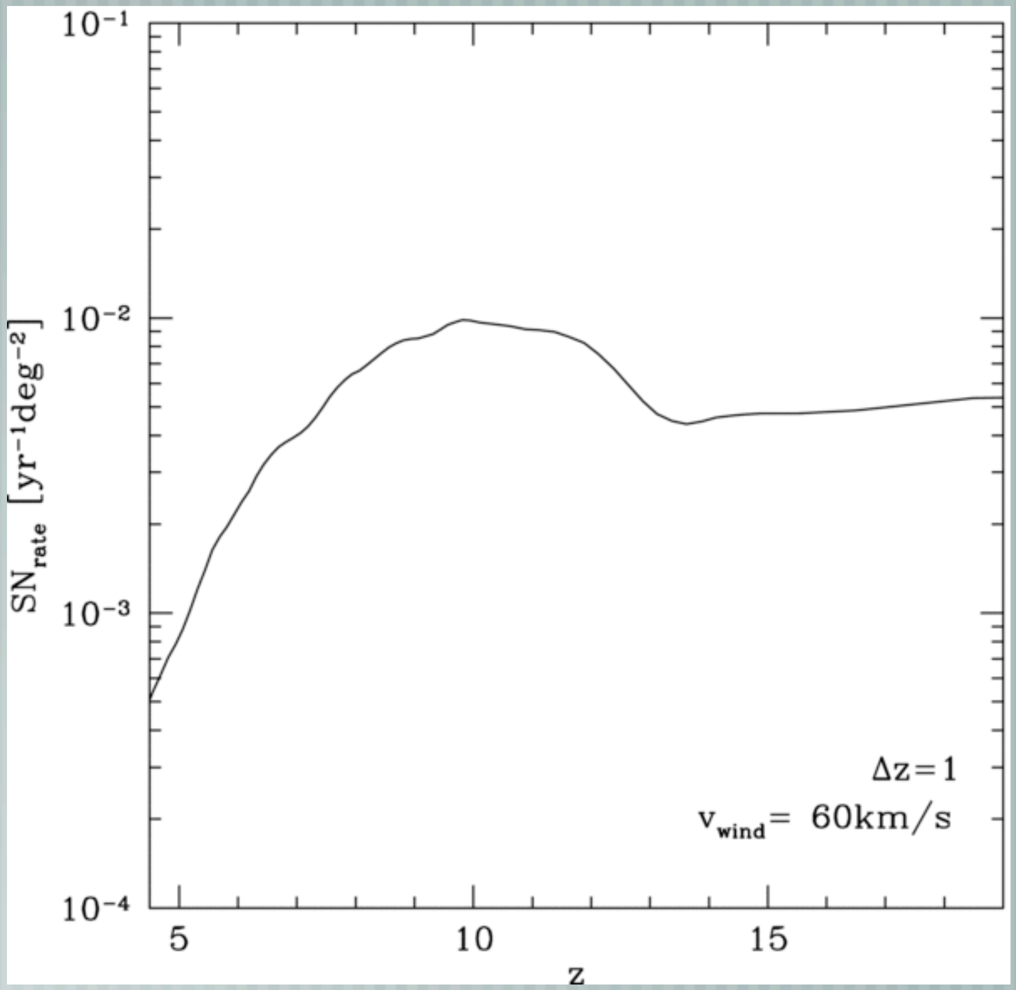


Trenti , Stiavelli & Shull (2009)

PopIII supernova rate

- PopIII stars at z>5 are very faint M_{AB}~38
  - little or no chance of direct imaging
- SN rate low (< 1/100 deg $^{-2}$ yr $^{-1}$)
  - but sources may be "bright" (M_{AB}~26)
  - LSST might have a chance to detect them at z~5

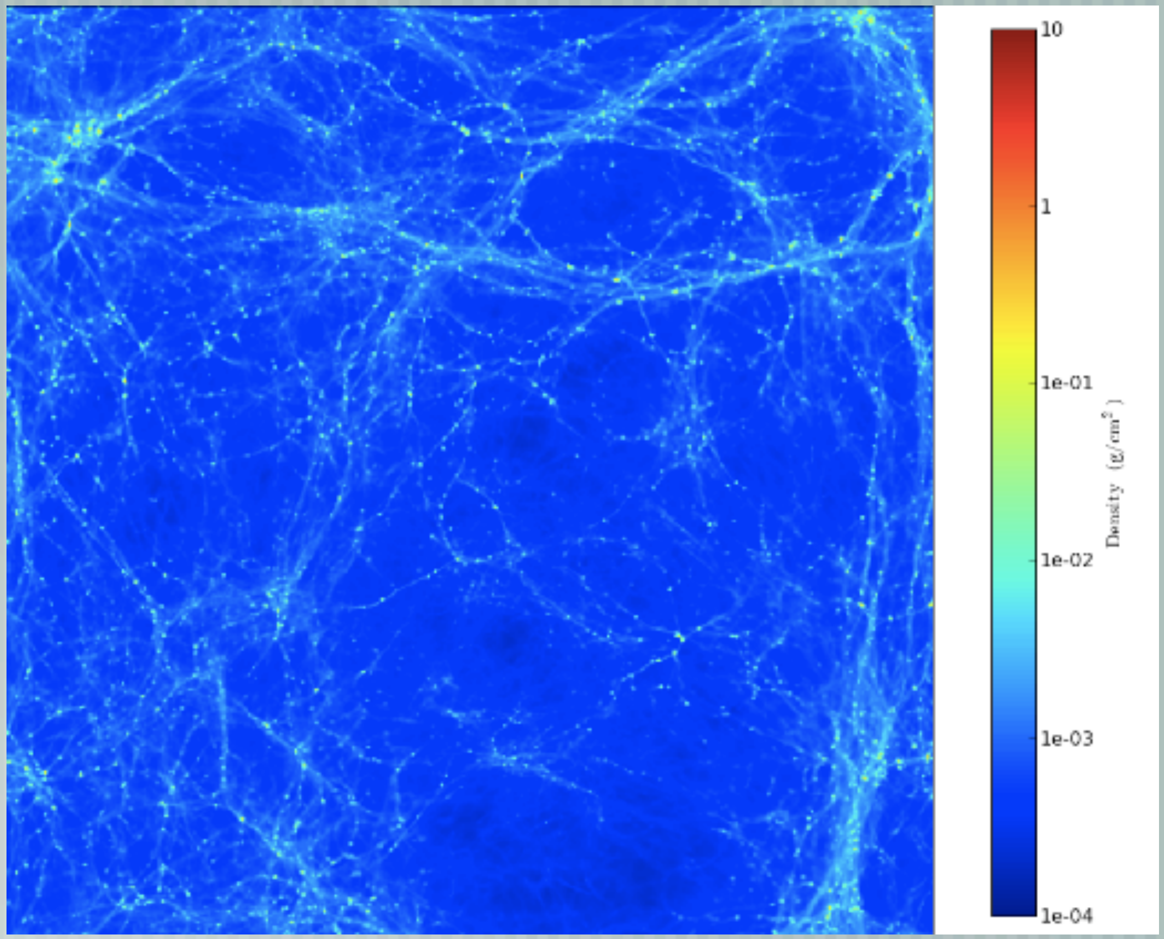
PopIII Supernova rate



Trenti , Stiavelli & Shull (2009)

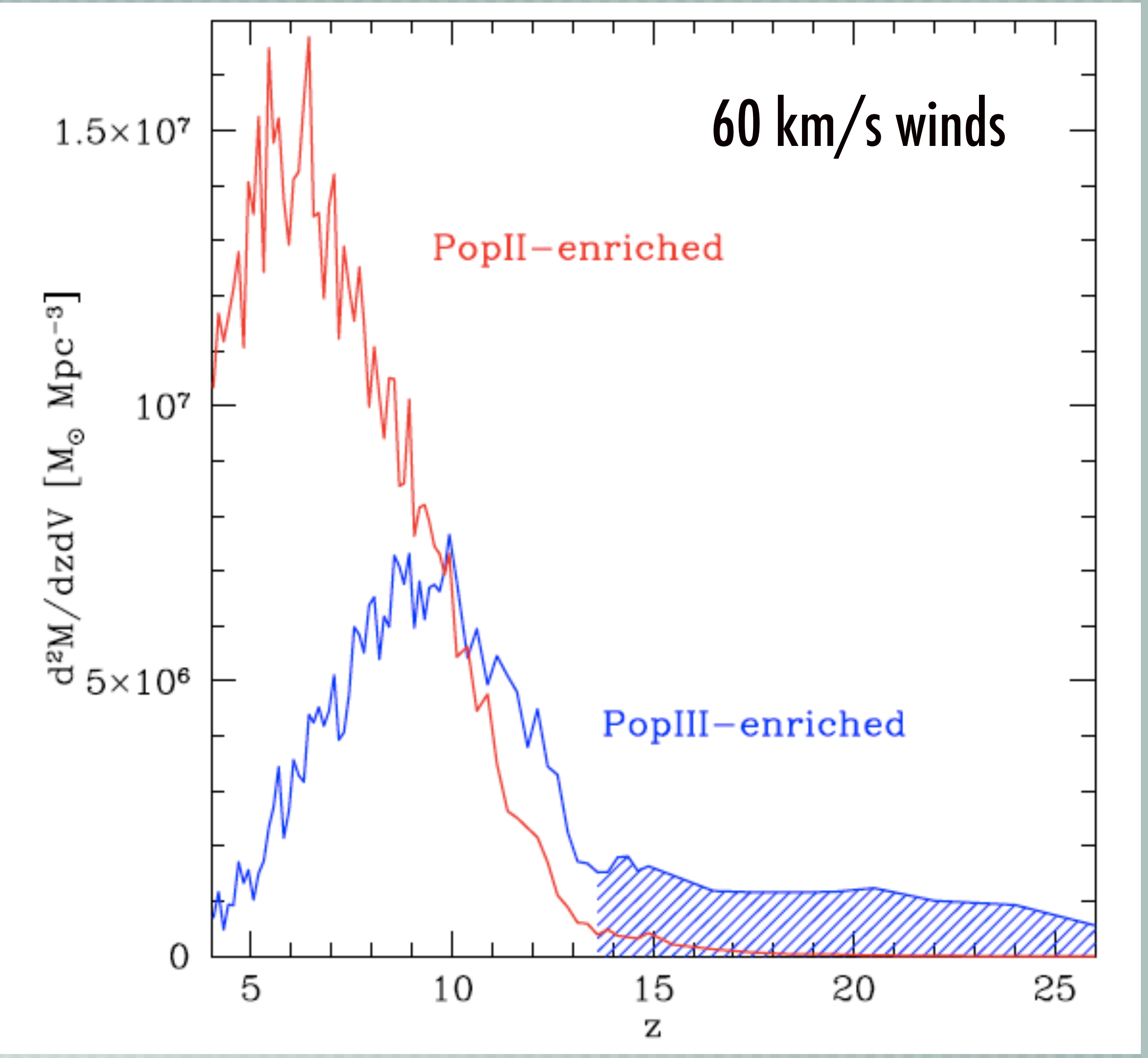
Chemical enrichment of the IGM

- When and how is gas enriched to Extremely Metal Poor ($Z \sim 10^{-3.5}$ Zsun) level?
  - Genetic Enrichment
  - Winds
- Cosmological simulations are needed to address this question



Extremely Metal Poor Gas

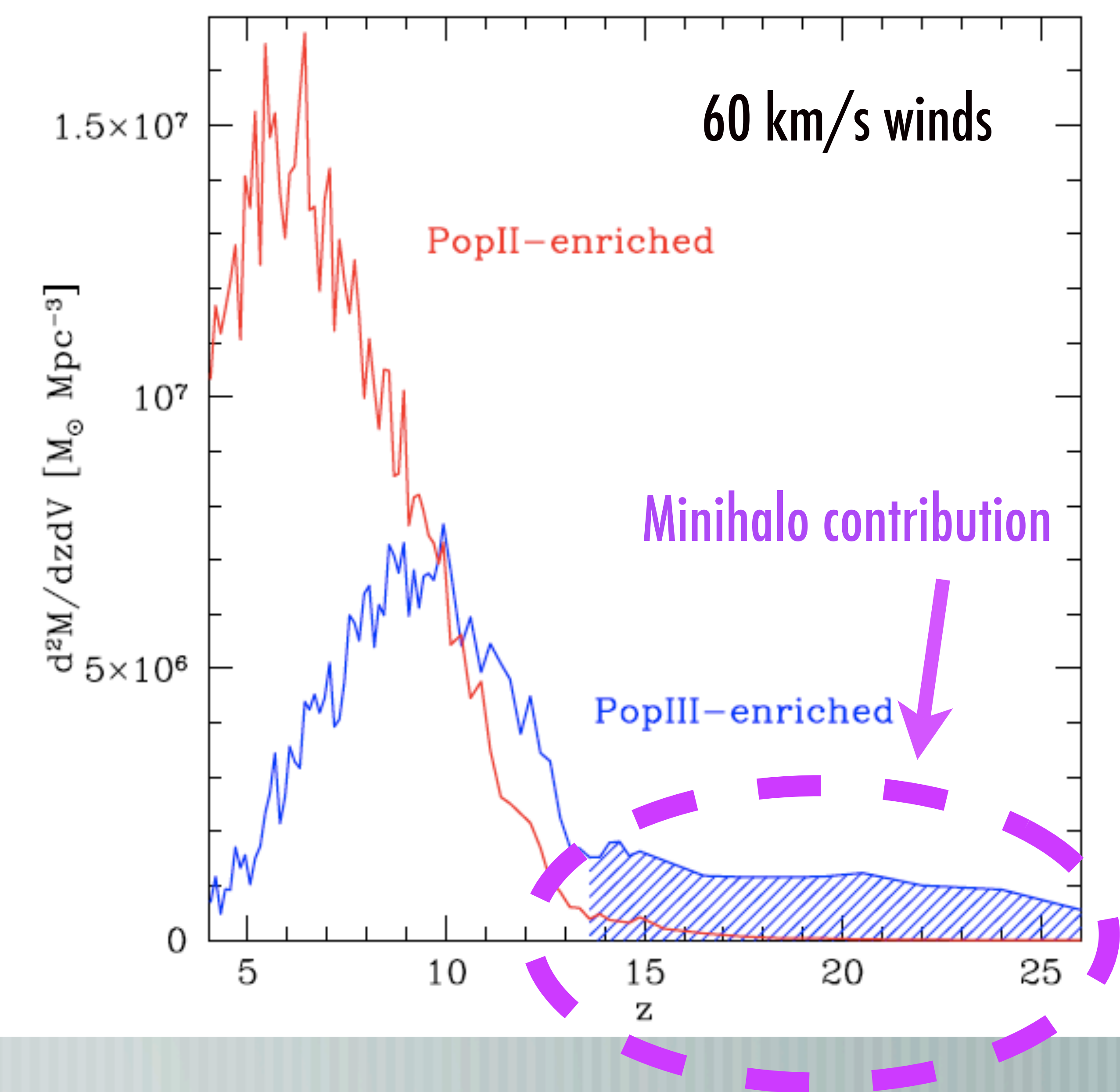
- Self-Enrichment from PopIII sources gives $Z \sim 10^{-3.5}$ Zsun
  - Peak at z~10
- Metal outflows from Pop II galaxies contaminate gas in nearby non self-enriched halos at z<15 (also to $Z \sim 10^{-3.5}$ Zsun)
  - Peak at z~6



Trenti & Shull (2010)

Extremely Metal Poor Gas

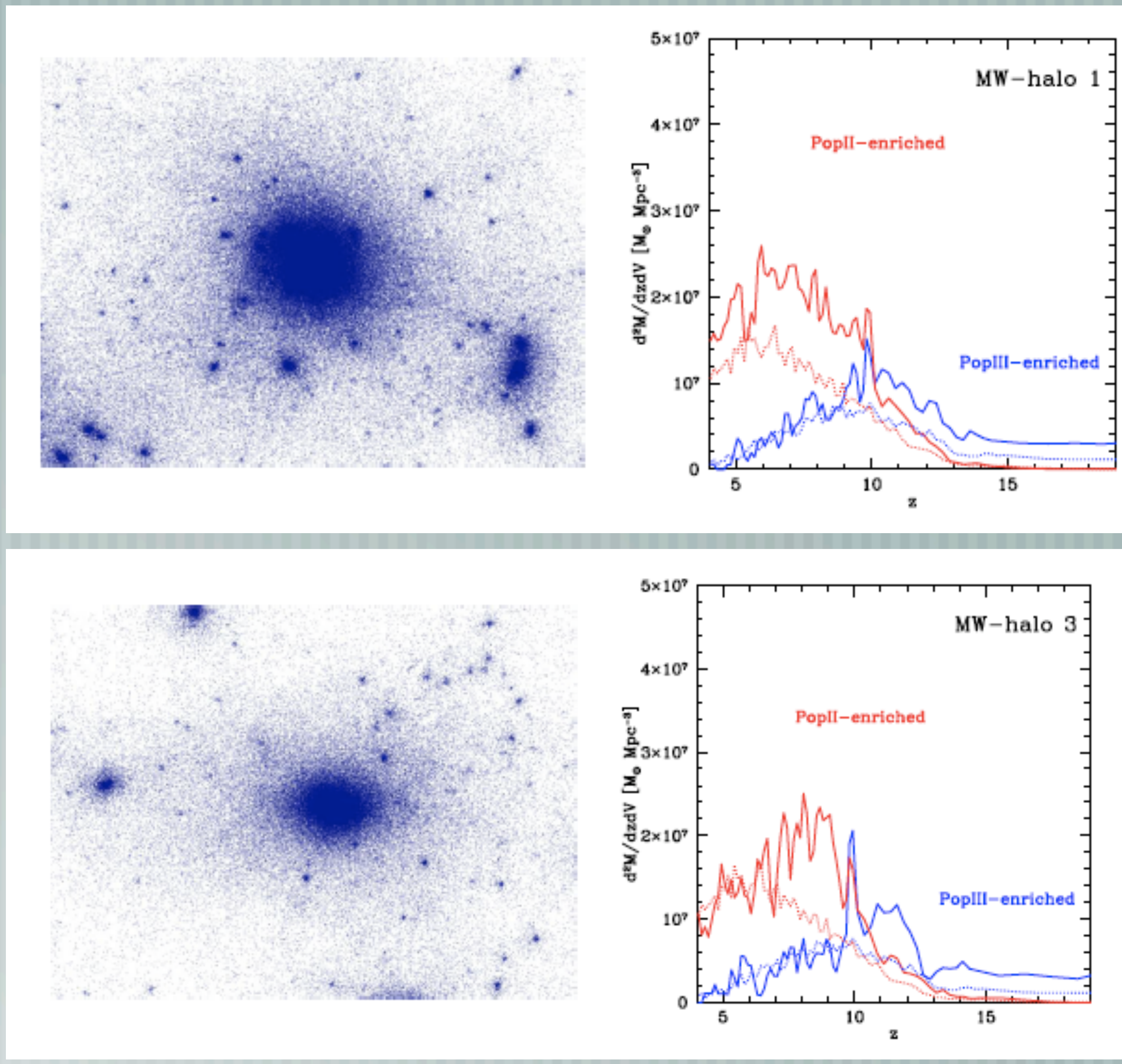
- The majority of the EMP gas is enriched by PopII stars, not PopIII
- In addition, PopIIIs in minihalos only enrich ~10% of the EMP gas (at z>14)
  - **EMP star abundance patterns probe IMF at z<10, not PopIII.1**



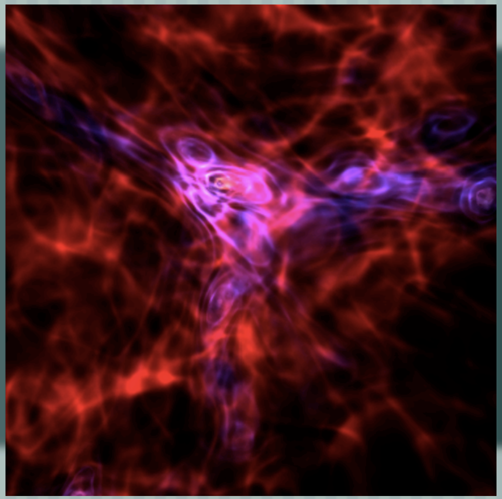
Trenti & Shull (2010)

EMP Gas in the Milky Way

- Milky Way progenitors live within overdensity at high-z, different from average region of the Universe
- Run series of simulations constrained to contain MW-like halo at their center (with $N=1024^3$, resolve minihalos)
- Star formation history and metal enrichment shifted at higher z, but qualitatively similar
    - most EMP gas still enriched by PopII winds



Trenti & Shull (2010)



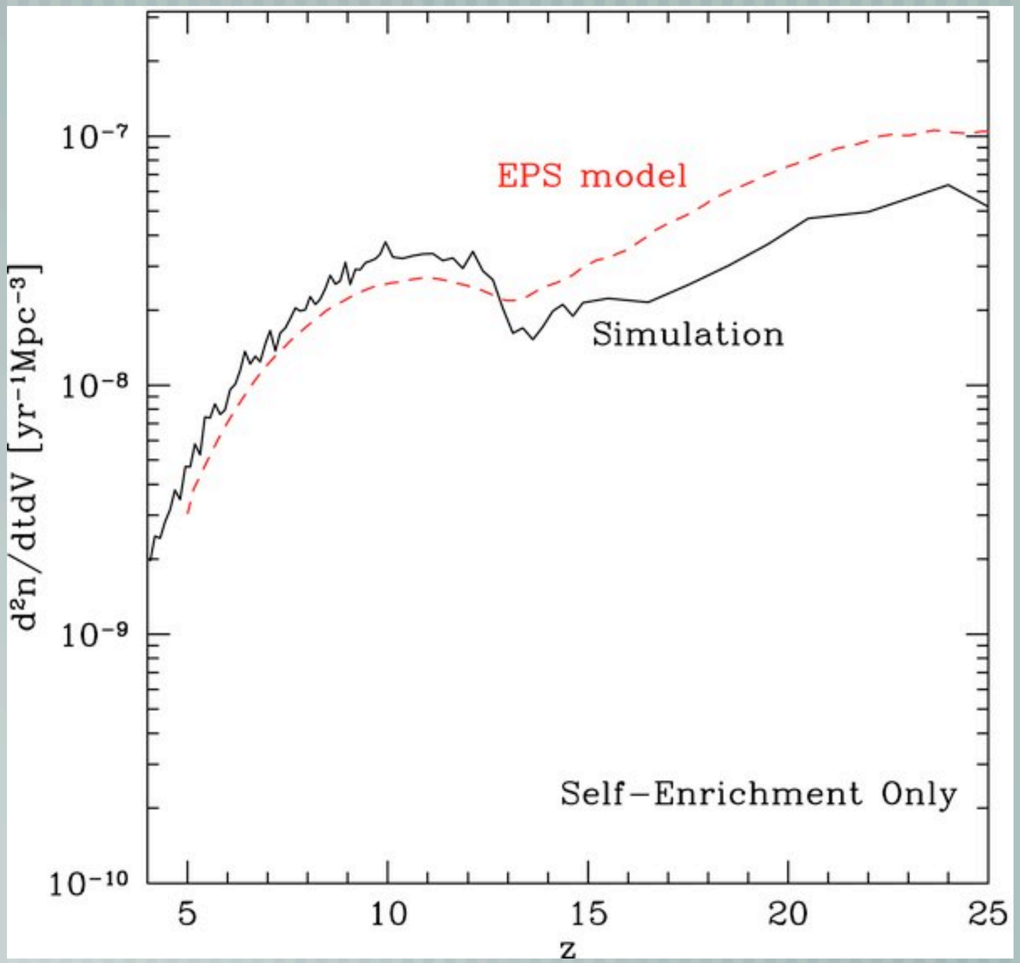
Summary

- The first Gyr after the Big Bang is characterized by a complex interplay between metal free (first stars) and metal enriched (first galaxies) star formation
  - PopIII/PopII transition highly inhomogenous: at z~5 metal free gas pockets still exist, but very low number density
- Pair Instability SNe at z<6 best chance to witness PopIII stars - if IMF allows them
- Majority of EMP gas is produced at z<10
- Galactic archeology probes primarily “low” redshift PopIII/PopII transition, not PopIII formation in minihalos, nor PopIII.1

PopIII stars at "low" redshift

- Convergence tests:
  - Cosmological simulation and analytical model agree well for self-enrichment scenario (no winds)
- To implement sub-grid physics, DM halos need to be resolved with N>100-400 particles
  - see Trenti et al. (2010), ApJ, 711, 1198

PopIII SFR:
analytical model vs. cosmological simulation

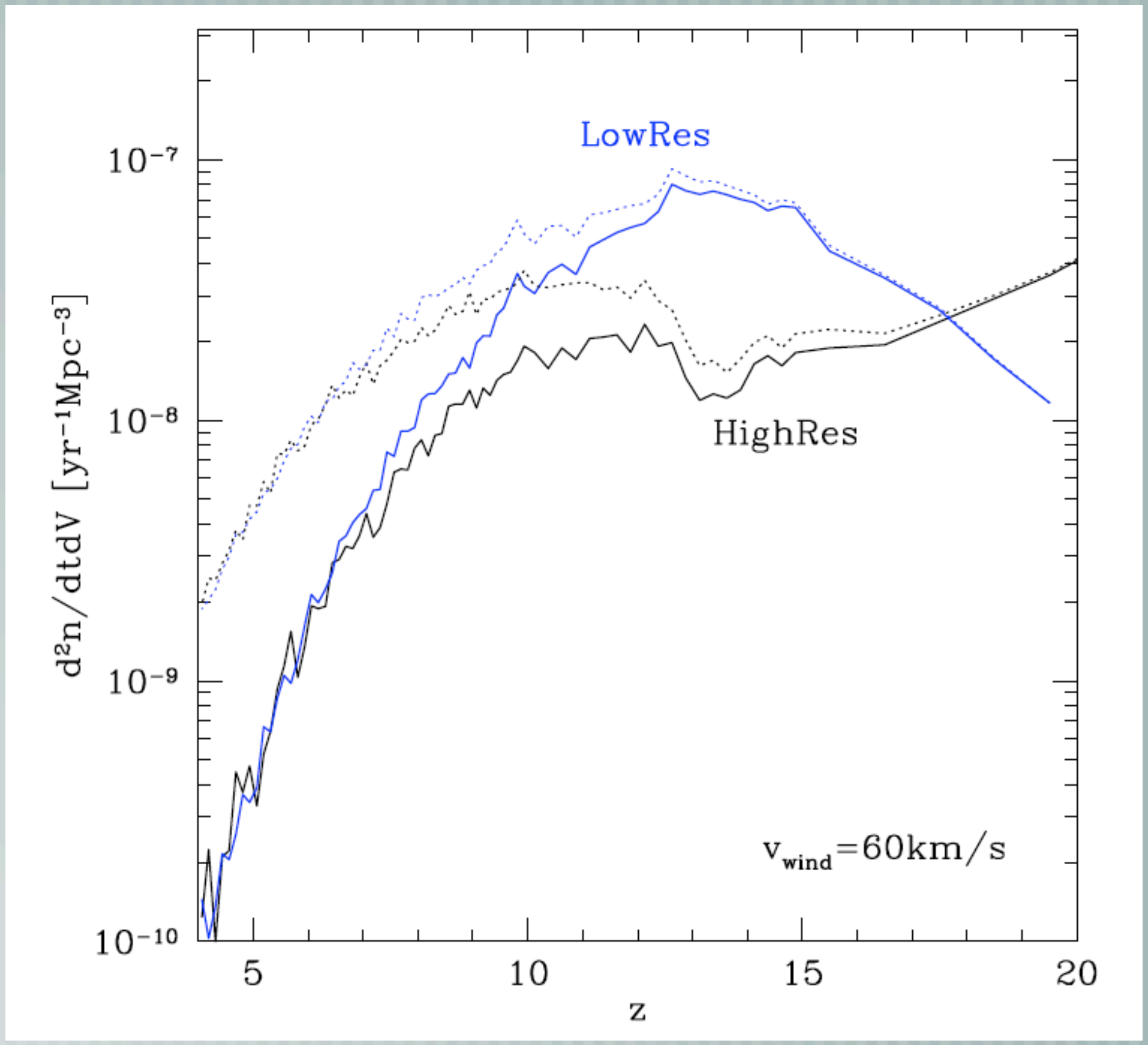


Trenti , Stiavelli & Shull (2009)

Resolution study: PopIII SFR

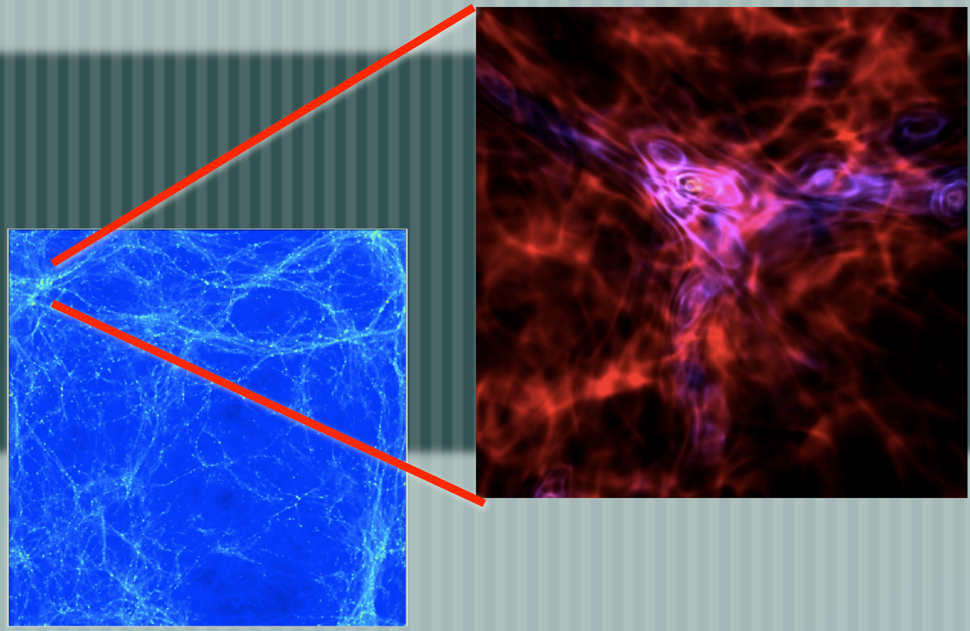
- If minihalos are not resolved, there is an artificial peak in PopIII SFR at z~13
  - 10^8 Msun halos appear chemically pristine without resolving progenitors

Resolution study: 512^3 vs. 1024^3



Trenti, Stiavelli & Shull (2009)

First Galaxies

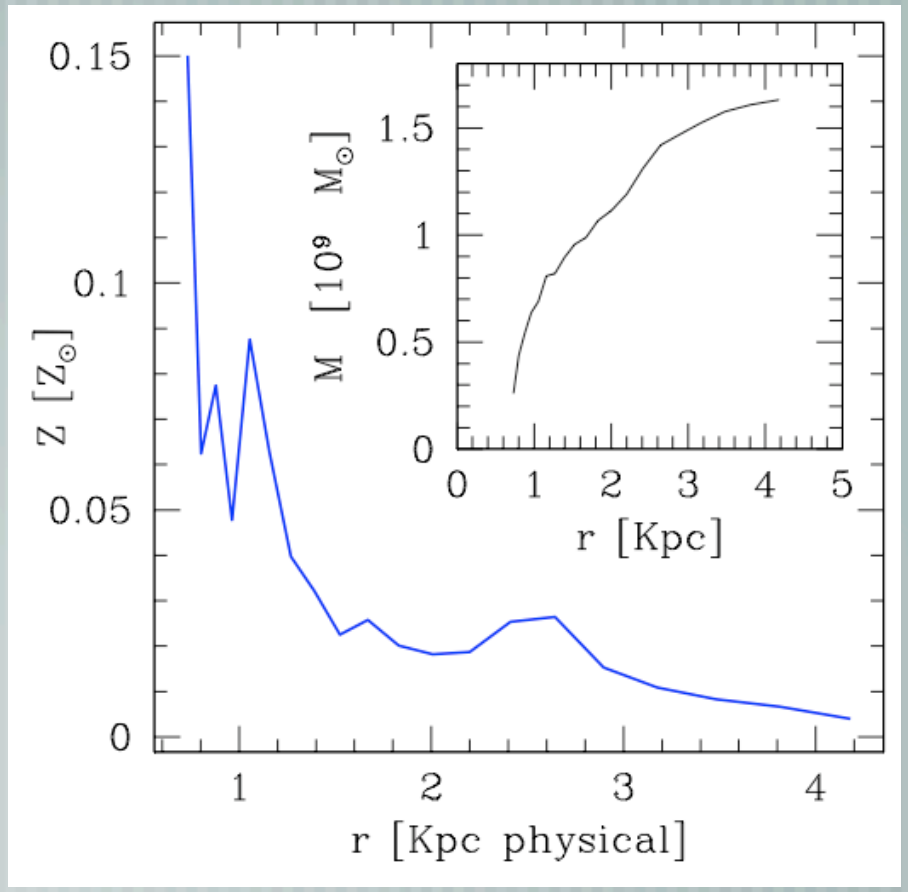


- Merging rapidly assembles the first galaxies: by z~8 halos with $M_{halo} > 10^{11}$ Msun are possible
  - Number density ~10^{-4} Mpc^3
- Typical WFC3/IR HST deep field probes 10^4 Mpc^3 at z~8
- Ab initio models/simulations meet observations!

Most massive galaxy

in N=2x1536^3(ENZO), l=25Mpc/h at z=8.5

DM Mass	1.5e11 Msun
Stellar Mass	1.6e9 Msun
<Z/Zsun>	0.02
<Stellar Age>	100Myr

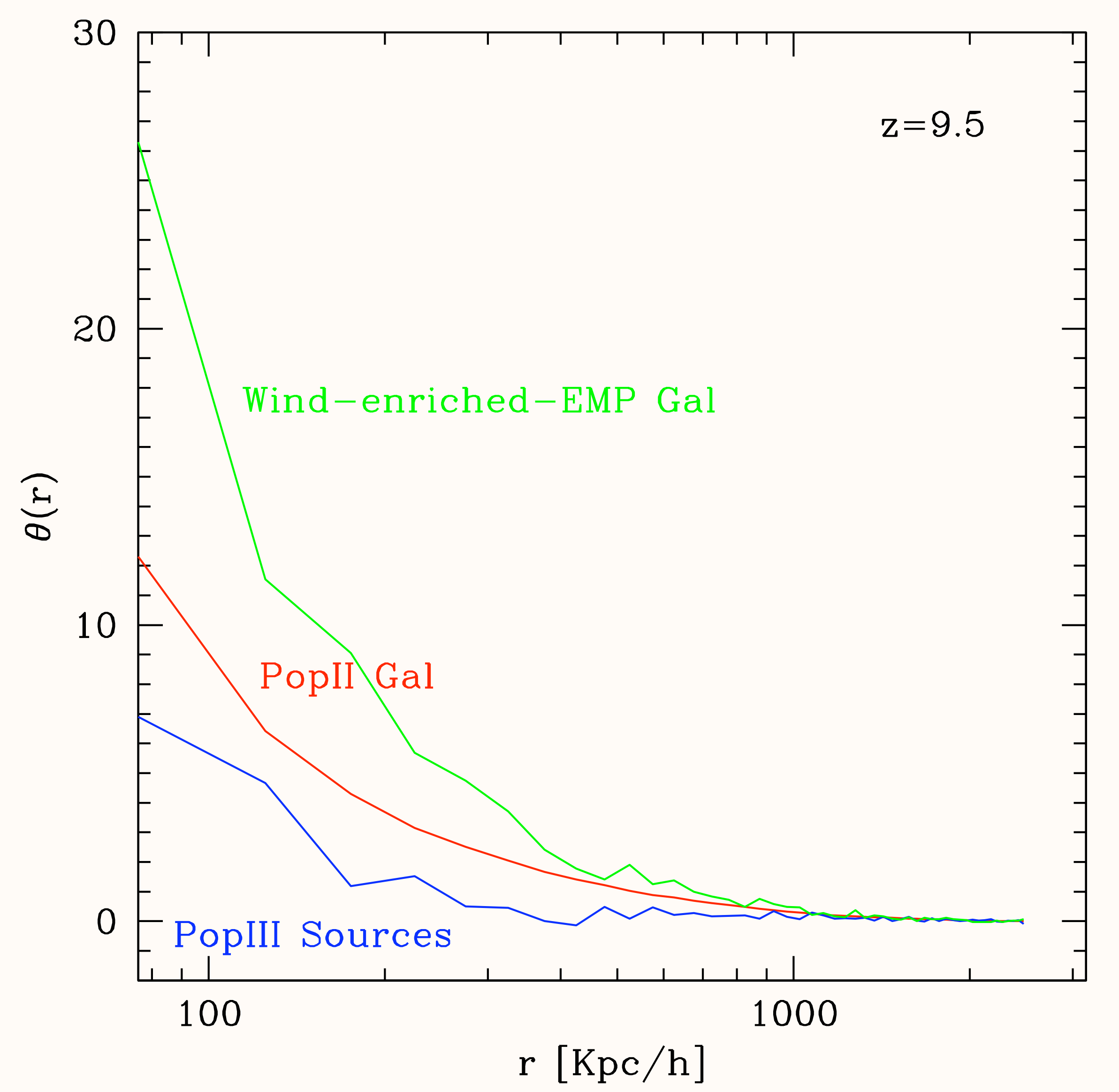


Trenti et al, in prep.

Clustering

- PopIII sources and the gas they enrich live in low bias regions
- EMP gas enriched by winds lives in high bias regions

Two point correlation function at z=9.5
10000 K< Tvir < 20000 K



Stiavelli & Trenti (2009)

PopIII formation with LW radiation

- Our analytical model for LW background effects compares well with AMR simulations of PopIII formation

Figures from O'Shea & Norman (2008)